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CONTAMINANTS PROGRAM



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CONTAMINANTS, FISH, AND HYDROLOGY OF THE MISSOURI RIVER AND WESTERN TRIBUTARIES, SOUTH DAKOTA

FINAL REPORT

BY

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Contaminants, Fish, and Hydrology of the Missouri River and Western Tributaries, South Dakota

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Abstract. We report on contaminants in sediments and biota, fish assemblages, and hydrology of the Missouri River and its western tributaries in South Dakota. Past mining activities and natural occurrences were identified as the primary contaminant sources in western rivers of South Dakota. Historical mining activities in the northern Black Hills discharged contaminants into streams, where they are still present. Elevated concentrations of arsenic and mercury related to ore processing activities were identified in the Whitewood Creek, the Belle Fourche River, the Cheyenne River, and the Missouri River, streams that sequentially flow into each other. Naturally occurring selenium from soil and rock formations was detected at elevated concentrations in sediments or biota in the Cheyenne River, Cheyenne River arm of Oahe Reservoir, Lake Francis Case, and Lewis and Clark Lake. Other contaminants detected above background levels were arsenic, barium, boron, chromium, mercury, manganese, nickel, and zinc. We make the following recommendations: (1) remediation of areas contaminated or affected by mine wastes—especially in the northern Black Hills—should continue, (2) monitoring of areas polluted with selenium should continue and environmental selenium should be confined to keep it from spreading, (3) siltation should be reduced by better land management in the watershed, (4) consideration should be given to increasing habitat diversity on the Missouri River in South Dakota, and (5) intensive fish sampling should be implemented on tributary streams to document current fish assemblages. Flow volumes in western Missouri River tributaries have historically fluctuated widely. Torrents of water flush through these streams following heavy precipitation events. The flows periodically drop to zero in all of the tributaries. Fish seemingly concentrate in deep pools during periods of low flow or move downstream to the Missouri River. The Missouri River provides a refuge for tributary stream fish during adverse periods. Fish species diversity in these

streams has decreased since samples were first collected before 1955, as compared with samples taken in 1980.

South Dakota is a relatively unpopulated state. It has only 696,004 residents according to the 1990 census. The distribution of people in South Dakota is polarized, with large populations located near Sioux Falls in the east and Rapid City in the west. The small amount of industry in the state is mostly located near these cities. Environmental contaminants associated with industry have the greatest potential to be found in the extreme eastern or extreme western parts of the state. Central South Dakota contains little manufacturing and is relatively contaminant free.

The Missouri River bisects South Dakota from north to south. All of the rivers in South Dakota flow into the Missouri River. The major tributary streams in the western part of the state flow from west to east before joining with the Missouri. These rivers flow mostly through relatively contaminant-free grassland areas used for hay production and grazing. However, there are contaminants in parts of the Black Hills and in some Black Hills streams. Contaminants can be transported great distances by water, and this study shows that contaminants found in western South Dakota are also present in the Missouri River.

There are three sources of contaminants in South Dakota: naturally occurring elements; industry, including mining; and agriculture. The greatest potential contaminant threat in western South Dakota to fish and wildlife is from inorganic chemicals such as arsenic and mercury produced by past Black Hills mining activities, and naturally occurring selenium.

Only limited studies have been conducted on the effects of contaminants in biota on fish distribution and abundance in western South Dakota streams. Evaluation of contaminants, hydrology, and biota in a watershed is needed to support management decisions.

The objectives of this paper are to identify contaminant distribution in sediment and biota, describe changes in fish assemblages, identify fluctuations in hydrologic conditions, and determine the biological significance of these variables in five principal watersheds associated with the Missouri River and its western tributaries in South Dakota.

Study Area

Major Contaminants

The Black Hills are located in extreme western South Dakota (Fig. 1). The Black Hills are, for the most part, contaminant-free and include 459,200 ha of National Forest and 234 km of trout streams. Industrial pollution is not a threat to most of the area. The creeks in the Black Hills generally consist of clear, cold, pollution-free water that flows over rock or gravel beds.

Mine wastes have caused water quality problems for some northern Black Hills streams for decades. Gold Run Creek, which contained a heavy load of mine wastes, flows into Whitewood Creek between the towns of Lead and Deadwood. Whitewood Creek was a clear, cold trout stream before becoming polluted with mine wastes. It is currently classified as a semipermanent warmwater stream. Whitewood Creek has a continuous water supply. Homestake Mine diverts water from Spearfish Creek for its own use and for Lead and Deadwood. Return flows from the mining company and the two towns, along with water from natural watershed flows and ground water from the Homestake Mine, all make up Whitewood Creek flows.

Large quantities of mining, milling, and ore processing wastes entered Whitewood Creek between 1875 and 1977 from mines operating in the northern Black Hills around Lead, South Dakota (Horowitz and Elrick 1990). About 100 million metric tons of mine tailings containing elevated concentrations of arsenic, mercury, and cyanide have been dumped into Whitewood Creek. In 1970, the U.S. Environmental Protection Agency revealed that 5.4 to 18.2 kg Hg/day were in the mine tailings slurry discharged into Whitewood Creek (U.S. Environmental Protection Agency 1971a).

Homestake Mining Company, the largest mine operator in the Black Hills, discontinued mercury use in December 1970. Homestake plant effluents still contained 1.13 kg Hg/day. Analyses of Homestake's effluent in June 1971 showed that daily loads of 141 kg of cyanide, 109 kg of zinc, 33 kg of copper, and about 3,000 tons of suspended solids were discharged into Whitewood Creek (U.S. Environmental Protection Agency 1971a).

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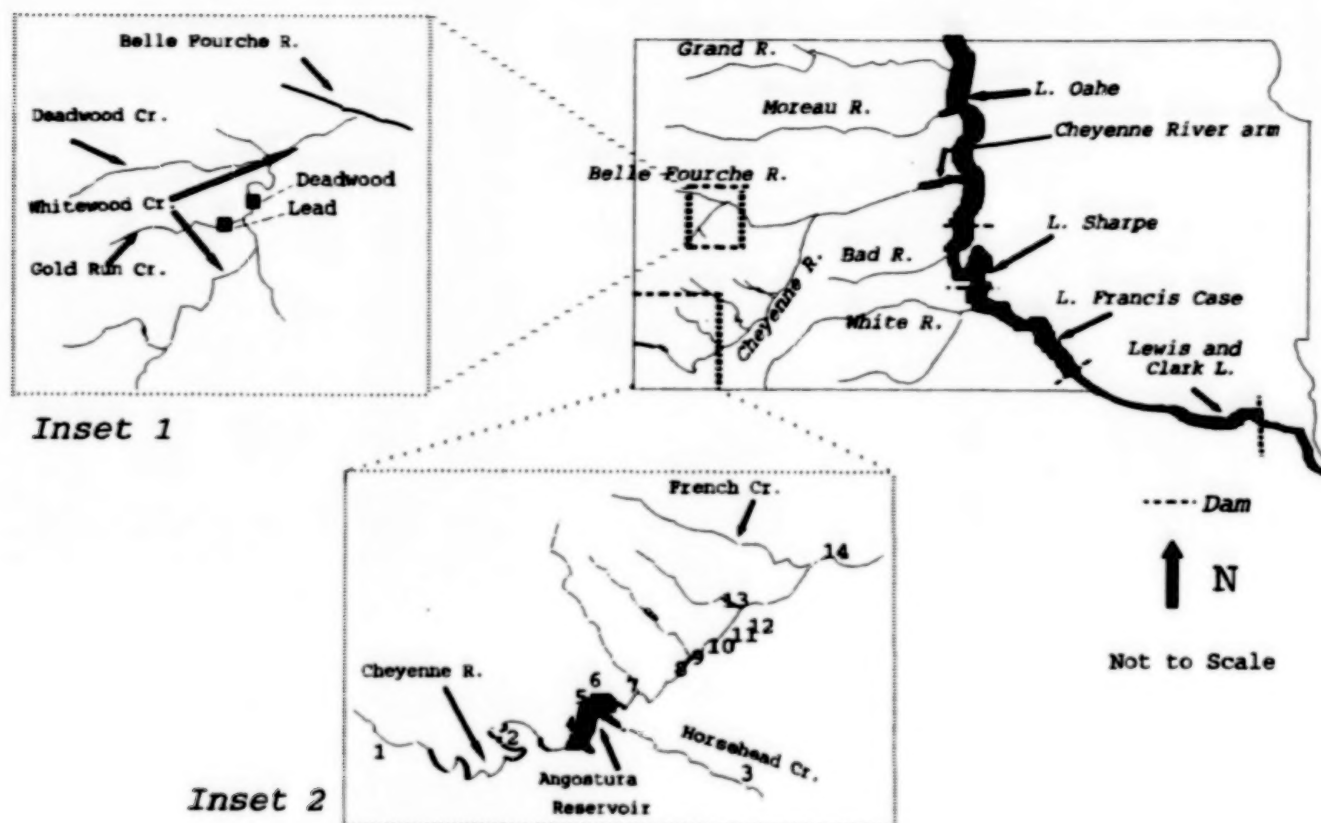


Fig. 1. Study area in western South Dakota. *Inset 1* shows the Gold Run and Whitewood Creek drainages and the mining area in the northern Black Hills. *Inset 2* shows numbers identifying fish and sediment sampling locations on the Cheyenne River.

In December 1977, Homestake constructed a dam across Whitewood Creek at Grizzly Gulch in an attempt to trap mine tailings and reduce pollutants downstream (U.S. Environmental Protection Agency 1990). However, mine tailings previously deposited along the Whitewood Creek banks continue to slough off into the creek.

Many Black Hills creeks have headwaters at higher elevations, drain easterly toward the foothills, and empty into either the Cheyenne or Belle Fourche River. Gold Run Creek enters Whitewood Creek near Lead, South Dakota. Selenium is not a wide-spread contaminant problem in the Black Hills; however, elevated selenium concentrations ($6.9 \mu\text{g/g}$) from an unknown source were detected in sediments at the mouth of Gold Run Creek (U.S. Geological Survey 1990).

Whitewood Creek flows northeast from the towns of Lead and Deadwood and enters the Belle Fourche River about 50 km to the northeast (Fig. 1). The Belle Fourche River is the largest stream in the northern Black Hills area. The same contaminants discharged into Whitewood Creek

have been detected at elevated concentrations in the Belle Fourche River (Roddy et al. 1991).

Mining occurred in the vicinity of Custer, Hill City, and Silver City in the southern Black Hills, but mercury was not widely used and is not a problem in the southern Black Hills. Selenium is not elevated in the southern Black Hills, but it is elevated in the prairie to the south.

The portion of the Cheyenne River watershed located south of Edgemont, South Dakota, contains marine shale that has elevated concentrations of selenium (Harris 1991). This selenium has been detected at relatively high concentrations in fish from Angostura Reservoir (Greene et al. 1990). Selenium is the only contaminant known to be elevated in the sediments and biota in the part of the Cheyenne River that receives drainage from the southern Black Hills.

The Cheyenne River is the largest western Missouri River tributary in the state. It flows northeasterly around the southern and eastern borders of the Black Hills and then merges with the Belle Fourche River about 80 km east of the Black Hills.

After merging with the Belle Fourche River, the Cheyenne River flows through sparsely populated badlands and prairie before entering the Cheyenne River arm of Oahe Reservoir, about 160 km to the east. Inorganic contaminants are present in some sections of the Cheyenne River. Mine wastes that affect water quality are carried to the Cheyenne River by the Belle Fourche River.

The Grand and Moreau rivers are located north of and parallel to the Cheyenne River. Both of these rivers flow to the east across the prairie and enter Oahe Reservoir (Fig. 1). The Bad River flows mostly through unaltered grassland prairie and enters the upper reaches of Lake Sharpe near Fort Pierre, South Dakota.

The White River watershed includes the badlands but is composed mostly of natural prairie. It enters Lake Francis Case near Chamberlain, South Dakota. The White River gets its name from the presence of off-white-colored suspended sediments that wash into the river from the badlands and other parts of the watershed. The Grand, Moreau, Bad, and White River drainages are relatively pollution free compared with the Cheyenne and Belle Fourche rivers.

Fish Assemblages

Knowledge of fish populations, and their change over time, in western tributaries of the Missouri River within South Dakota is limited. Fishery data collected or summarized by Churchill and Over (1933) and Bailey and Allum (1962) provided the available information on the existence of fish species within these river basins before impoundment of the Missouri River mainstem in South Dakota.

Fish population studies on tributary river basins, following completion of Missouri River mainstem impoundments, were limited primarily to work conducted on individual reservoirs. Documented fish assemblages before 1955 were compared with populations present within the drainage since 1980 (Appendix Table 1). Sturgeons, paddlefish, percids, and various centrarchids, while not documented in each tributary in earlier works (Churchill and Over 1933; Bailey and Allum 1962), were known to be present in the Missouri River and were suspected of inhabiting all of these tributaries under certain flow conditions.

Hydrology

Flow volumes in the western tributaries to the Missouri River vary widely between seasons and

between years, with long periods of low flow interrupted periodically by water torrents flushing rapidly through the systems during periods of snow melt and following heavy rains (Appendix Table 2). Flows can range from over bank full to dry at many tributary sites during a year. The Missouri River provides a refuge for tributary fish during periods of low flow. The fish escape to the larger river, wait out the adverse conditions, and return to the same or a different tributary when flows resume. After reservoir construction; however, the amount of river habitat suitable as a refuge for temporarily dislocated stream fish in the impounded sections of the Missouri River declined. The change in habitat and habitat diversity on the Missouri River is believed to be partially responsible for the decline in the number of fish species present in tributary streams.

Tributary streams provide spawning and nursery areas for fish that inhabit the mainstem Missouri River. The Grand, Moreau, and Cheyenne rivers were exclusive spawning grounds for goldeye, walleye, sauger, white sucker, and minnows (*Hybognathus* spp.) and major spawning areas for white bass, buffalo, and carp (Nelson 1980). Nelson reported that young fish production was strongly correlated with river flow volume, which flooded terrestrial vegetation during the spawning season.

Normal precipitation amounts for selected portions of South Dakota, based on data from 1951 to 1980, are shown in Fig. 2. Western South Dakota is arid. The Black Hills region receives the most precipitation of any part of the state west of the Missouri River, averaging 54.1 cm yearly (U.S. Geological Survey 1992). The southwest and central regions receive the lowest annual rainfall, 42.21 and 42.93 cm (Fig. 2). Most precipitation occurs during the period April-June. These precipitation patterns determine stream flows of the western Missouri River tributaries. Selected hydrologic and basin characteristics for Missouri River tributaries are shown in Appendix Table 2.

Methods

Sediments and Shale

Sediment samples were collected in 1980 from lakes Oahe, Sharp, and Francis Case and were analyzed as described by Phillips et al. (1987).

In 1984, sediment grab samples were collected, by U.S. Fish and Wildlife Service personnel, from

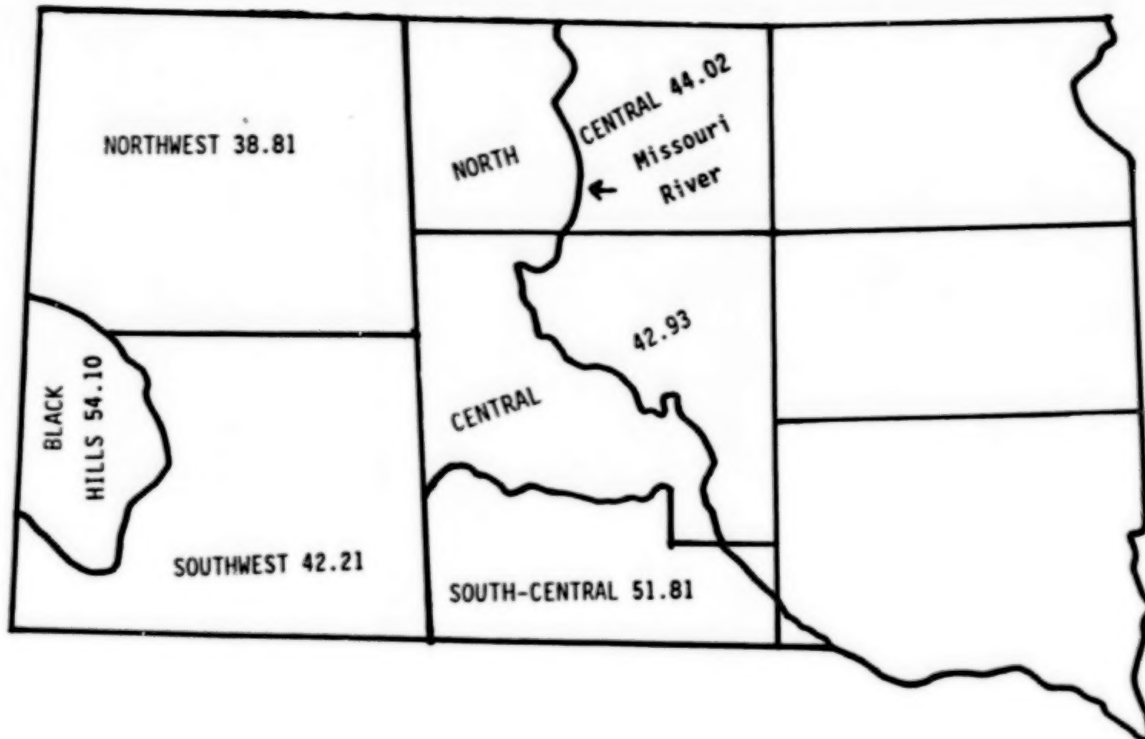


Fig. 2. Normal annual precipitation amounts in centimeters for selected regions of South Dakota (U.S. Geological Survey 1992).

a transect across Foster Bay on the Cheyenne River arm of Oahe Reservoir. Sediments were analyzed by the Environmental Trace Substances Research Center, Columbia, Missouri, for arsenic, mercury, and selenium.

In 1990, U.S. Fish and Wildlife Service personnel collected composite surface sediment samples from areas bordering Missouri River islands. Four to six subsamples were placed in an acetone-rinsed stainless steel bowl, mixed, then spooned into acid-cleaned glass jars and capped with teflon-lined lids for storage. Sediment samples were frozen at our laboratory and shipped on dry ice to the Research Triangle Institute, Research Triangle Park, North Carolina, where they were analyzed for arsenic, mercury, selenium, and nine other inorganic elements.

Cheyenne River sediments were collected and analyzed by the U.S. Geological Survey Geochemistry Laboratory, Lakewood, Colorado, as described by Greene et al. (1990). Sediment sampling locations on the Cheyenne River are identified in Appendix Table 3. Sediment samples from the Belle Fourche River were collected and analyzed as described by Roddy et al. (1991). Sediment sam-

pling locations in the Belle Fourche River are described in Appendix Table 4.

In 1991, Service personnel collected sediment samples from two or more locations on the major western Missouri River tributaries. Collection locations were spaced so that the samples would be representative of sediments throughout the drainage. Sediment samples from tributaries were collected from the upper 10 cm of bottom substrate using a stainless steel scoop, a stainless steel spoon, or an Ekman dredge. Sediments were analyzed for 12 inorganic elements by the Hygienic Laboratory at the University of Iowa, Iowa City.

In May and June 1990, shale samples were collected from above the water line on six bluffs bordering Lewis and Clark Lake and the Missouri River. Bluffs sampled were selected based on size, accessibility, amount of exposed surface, and location. Unweathered shale samples were collected by digging 10 to 15 cm into the bluffs and removing a dry sample. Composite shale samples consisting of four to six subsamples each were stored in acid-cleaned jars capped with teflon-lined lids. Shale samples were analyzed for cadmium and selenium by the Research Triangle Institute.

Birds

Adult and juvenile double-crested cormorants (*Phalacrocorax auritus*) were collected from Foster Bay on the Cheyenne River arm of Oahe Reservoir using a shotgun. Livers were removed, frozen, and shipped to the Patuxent Wildlife Research Center, Laurel, Maryland, where they were analyzed for mercury and selenium.

Fish

The common and scientific names of fish referenced in this study are listed in Appendix Table 5. In 1970-71, northern pike, walleye, channel catfish, and common carp were collected in gillnets and trapnets from Foster Bay on the Cheyenne River arm of Oahe Reservoir, Whitlock Bay on Oahe Reservoir, and Oahe Reservoir tailwaters and analyzed for mercury by the U.S. Environmental Protection Agency, Kansas City, Missouri, as described by the U.S. Environmental Protection Agency (1971b). In 1984, northern pike, walleye, channel catfish, and common carp were collected from Foster Bay on the Cheyenne River arm of Oahe Reservoir and analyzed for mercury, arsenic, and selenium, as described by Sowards (1985).

Fish were collected from the Cheyenne River in 1985-86 and from the Belle Fourche River and Horse Creek in 1988 using electrofishing equipment. Fish sampling locations on the Cheyenne River and Belle Fourche River are described in Appendix Tables 3 and 4. Fish collected were from two different trophic levels—bottom feeders (shorthead redhorse, common carp) and pelagic feeders (flathead chub). Tributary stream fish were analyzed (whole body) for inorganic elements by the University of Missouri Environmental Trace Substance Research Center, Columbia, or by Hazleton Laboratories of America, Inc., Madison, Wisconsin.

In 1990, we used a seine to collect forage fish samples, consisting of emerald shiners, red shiners, spotfin shiners, and largemouth bass, from waters bordering Missouri River islands. The fish were stored in labeled food-quality plastic bags. Forage fish were analyzed (whole body) for 10 inorganic elements by the Research Triangle Institute.

All fish and the cormorant tissues were analyzed according to methods approved by the U.S. Environmental Protection Agency or the Patuxent Analytical Control Facility. Tissues and sediments were analyzed for arsenic and selenium by hydride

generation, atomic absorption, and for mercury by cold-vapor atomic absorption spectroscopy. The other elements were analyzed by the inductively coupled plasma emission spectrometry method.

In 1967, the Service initiated a National Contaminant Biomonitoring Program (NCBP). Under the NCBP, fish were collected from randomly selected sites throughout the United States and analyzed for organic and inorganic contaminants. The NCBP provides baseline data for comparing contaminant concentrations in fish that are not related to toxicity values. Analytical results for our fish were compared with the NCBP 85th percentile data. Concentrations in fish are considered elevated when they exceed the 85th percentile of the nationwide geometric mean (Lowe et al. 1985).

Results and Discussion

Whitewood Creek

Sediments

Low background concentrations of arsenic (20.0 µg/g), mercury (0.19 µg/g), and selenium (1.20 µg/g) were present in Whitewood Creek sediments collected upstream from Lead between 1986 and 1988 (U.S. Geological Survey 1990). Concentrations of these elements were elevated in sediments collected downstream from Lead—maximum concentrations were 23,500 µg/g of arsenic, 1.73 µg/g of mercury, and 6.05 µg/g of selenium.

Fish Contaminants

In 1971, brook trout, white sucker, and longnose dace collected from Whitewood Creek upstream from its confluence with Gold Run Creek contained <0.04 µg/g wet weight of mercury (U.S. Environmental Protection Agency 1971a). In this same study, no aquatic organisms were found in Gold Run Creek or in Whitewood Creek downstream from its confluence with Gold Run Creek. The U.S. Environmental Protection Agency (1971a) reported that cyanide, arsenic, mercury, and suspended solids were each elevated enough so that independently or combined they could damage Whitewood Creek biota. Damage to biota extended into the Belle Fourche River downstream from the mouth of Whitewood Creek.

Belle Fourche River

Sediments

Concentrations of arsenic in sediments from unpolluted areas generally seemed to be less than 10 $\mu\text{g/g}$ (Martin and Hartman 1984). Arsenic concentrations in Belle Fourche River drainage sediments ranged from 5.9 to 370.0 $\mu\text{g/g}$ (Appendix Table 6) and were highly elevated compared with western U.S. soils (Shacklette and Boerngen 1984), northern Great Plains soils (Severson and Tidball 1979), or wetlands in the northern prairie region of the United States (Martin and Hartman 1984). The highest concentration of arsenic (370 $\mu\text{g/g}$) was detected in sediments at site 18 (Belle Fourche River near Sturgis).

Boron, cadmium, lead, and molybdenum concentrations in sediments from all Belle Fourche River stations were within the normal range reported for western U.S. soils (Shacklette and Boerngen 1984). Zinc, manganese, and nickel were elevated in sediments at most sites. At site 12 (Horse Creek above Vale), chromium and selenium were elevated in sediments, and at site 18, manganese, selenium, and nickel were elevated compared with values reported for western U.S. soils (Shacklette and Boerngen 1984).

Selenium in Belle Fourche River sediments ranged from 0.6 to 3.5 $\mu\text{g/g}$. Sediment samples from all sites had selenium concentrations below the 4.0- $\mu\text{g/g}$ level of concern for bioaccumulation (Lemly and Smith 1987).

Mercury concentrations in all Belle Fourche River drainage sediment samples (Appendix Table 6) were low and less than or near the geometric mean concentration reported for western U.S. soils (Shacklette and Boerngen 1984).

Fish Contaminants

Arsenic is a nonessential element. Exposure to arsenic can reduce growth or increase mortality in aquatic organisms (Oladimeji et al. 1984). Arsenic is rapidly excreted after exposure (Eisler 1988); therefore, there is evidence that it does not readily bioaccumulate (Moore and Ramamoorthy 1984). Elevated concentrations of arsenic have, however, been documented in trout (Osmundson 1992; T. Chapman, South Dakota Department of Game, Fish, and Parks, personal communication).

In the Belle Fourche River, arsenic concentrations were relatively low and less than the NCBP 85th percentile concentration of 0.22 $\mu\text{g/g}$ wet weight or about 0.88 $\mu\text{g/g}$ dry weight (Lowe et al.

1985) in fish from all stations except for 12 and 18 (Appendix Table 7). Arsenic was highest in fish from station 18, where concentrations ranged from 1.3 to 7.6 $\mu\text{g/g}$ (dry weight).

In fish tissues, mercury concentrations in excess of 1.10 $\mu\text{g/g}$ wet weight should be considered evidence of an environmental mercury problem (Eisler 1987). For the protection of piscivorous mammals and birds, total mercury concentrations in their foods should probably not exceed 0.10 $\mu\text{g/g}$ wet weight for birds and 1.10 $\mu\text{g/g}$ wet weight for small mammals (Eisler 1987). The NCBP geometric mean for mercury in fish is 0.10 $\mu\text{g/g}$ wet weight (0.40 $\mu\text{g/g}$ dry weight; Schmitt and Brumbaugh 1990). For the Belle Fourche River, most fish from stations 2 and 12 (Appendix Table 7) had mercury concentrations below 0.40 $\mu\text{g/g}$ dry weight, which is the maximum dietary concentration for the protection of birds. Most of the fish from station 18 had mercury concentrations that exceeded the NCBP geometric mean (Appendix Table 7).

Selenium concentrations in fish from station 2 on the Belle Fourche River (Appendix Table 7) were close to the NCBP 85th percentile concentration of about 2.8 $\mu\text{g/g}$ dry weight (Lowe et al. 1985).

Most flathead chub from station 12 had selenium concentrations near or greater than the NCBP concentration of 2.8 $\mu\text{g/g}$. However, selenium concentrations in most of the shorthead redhorse from station 12 were close to the NCBP concentration. Common carp and shorthead redhorse from station 18 had selenium concentrations that exceeded the NCBP concentration (Appendix Table 7).

Cadmium in 10 Belle Fourche River fish samples slightly exceeded the NCBP 85th percentile dry weight concentration of about 0.36 $\mu\text{g/g}$ (Lowe et al. 1985). Concentrations of copper and zinc in common carp from the Belle Fourche River exceeded the NCBP 85th percentile dry weight concentrations of about 4.56 $\mu\text{g/g}$ and 185.04 $\mu\text{g/g}$, respectively. Common carp normally accumulate much higher concentrations of zinc than do other fish from the same water (Lowe et al. 1985).

Lead concentrations in most fish samples from the Belle Fourche River were below the NCBP 85th percentile dry weight concentration of about 1.28 $\mu\text{g/g}$ (Lowe et al. 1985). Lead concentrations in only one fish sample slightly exceeded the NCBP geometric mean.

Cheyenne River

Sediments

Cadmium was present in sediments at only one of nine sites on the Cheyenne River at a detection level of 2.0 $\mu\text{g/g}$ (Appendix Table 8). Arsenic concentrations in Cheyenne River sediments were elevated (6.2 to 15.0 $\mu\text{g/g}$) compared with geometric means reported for western U.S. soils (Shacklette and Boerngen 1984).

Mercury in Cheyenne River sediments was detected in seven of nine samples; however, the concentrations detected were all low (≤ 0.04 $\mu\text{g/g}$). Selenium in sediment samples from all Cheyenne River drainage sites was below the 4 $\mu\text{g/g}$ level of concern for bioaccumulation (Lemly and Smith 1987), except at sites 8 and 13, where 4.30 $\mu\text{g/g}$ and 14.00 $\mu\text{g/g}$, respectively, were detected. Barium concentrations in Cheyenne River sediments exceeded the values reported for western soils by Shacklette and Boerngen (1984) at all sites except 4, 6, and 13. Concentrations of barium, lead, manganese, nickel, and zinc (Appendix Table 8) were higher at most Cheyenne River locations than those reported for western U.S. soils (Appendix Table 9) by Shacklette and Boerngen (1984). Concentrations of molybdenum in the Cheyenne River sediments from most sites were below those reported for western U.S. soils.

Fish Contaminants

All but one fish from Cheyenne River stations 1 and 12 and most fish from station 14 had arsenic concentrations equal to or less than the NCBP 85th percentile value of 0.88 $\mu\text{g/g}$ dry weight (Appendix Table 10). Mercury concentrations in all but seven Cheyenne River fish were less than the 0.40- $\mu\text{g/g}$ NCBP geometric mean value (Appendix Table 10). The Cheyenne River drains some areas that are known to be high in selenium (Harris 1991). The highest selenium concentrations (2.1 to 10.0 $\mu\text{g/g}$) detected in this study were in Cheyenne River fish. Selenium concentrations in fish from all Cheyenne River stations exceeded the NCBP 85th percentile concentration of about 2.8 $\mu\text{g/g}$ dry weight (Lowe et al. 1985).

Cadmium was not detected in 19 of 60 fish samples analyzed from the Cheyenne River (Appendix Table 10). Cadmium concentrations in only five fish samples from the Cheyenne River were greater than the NCBP 85th percentile dry weight concentration of about 0.36 $\mu\text{g/g}$. Copper concentrations in 20 of 60 Cheyenne River fish samples

exceeded the NCBP 85th percentile dry weight concentration of about 4.56 $\mu\text{g/g}$. In flathead chub and shorthead redhorse, copper concentrations were lower (with the exception of one shorthead redhorse) than the NCBP concentration. Zinc concentrations in most common carp exceeded the NCBP 85th percentile dry weight concentration of about 185 $\mu\text{g/g}$. In flathead chub and shorthead redhorse, zinc concentrations were all lower than the NCBP concentration.

Fish Assemblages

Thirty-one fish species (Appendix Table 1) were historically documented (Churchill and Over 1933; Bailey and Allum 1962) from the Cheyenne River drainage, which included over 320 km of coldwater streams (South Dakota Department of Natural Resources 1975). All trout species, common carp, golden shiner, largemouth bass, and plains killifish are nonnative to the drainage. Koth and Ford (1980) sampled the upper portion of the basin and collected 15 species (Appendix Table 1), all previously documented. Fish collections from the adjacent Missouri River since 1980 (Riis et al. 1988; Johnson et al. 1991) documented 15 of the non-trout species identified in the earlier collections. Four species, finescale dace, longnose sucker, sicklefin chub, and sturgeon chub, are currently on the state's threatened list (Ashton and Dowd 1991).

Grand River

Sediments

Arsenic, manganese, and nickel in sediment samples from the Grand River (Appendix Table 11) exceeded the geometric means for these elements in western U.S. soils (Shacklette and Boerngen 1984) and northern Great Plains soils (Severson and Tidball 1979). Mercury, selenium, and cadmium were not identified in sediments from the Grand River at the detection level.

Fish Assemblages

Thirty-two species of fish (Appendix Table 1) were documented from the Grand River drainage before 1955 (Churchill and Over 1933; Bailey and Allum 1962). All fish collected, with the exception of bluntnose minnow, common carp, and largemouth bass, were considered native to the drainage. In post-1980 samples from the Grand River, Riis et al. (1988) and Johnson et al. (1991) reported 21 of the same species known to be in Lake Oahe before 1955 (Appendix Table 1). Two species, the

sturgeon chub and sicklefin chub, are on the state threatened list, while the pallid sturgeon is listed on state and federal endangered species lists. The fate of the other eight species is unknown.

Moreau River

Sediments

Arsenic and nickel in sediment samples from the Moreau River (Appendix Table 11) exceeded the geometric mean for these elements in western U.S. soils (Shacklette and Boerngen 1984) and northern Great Plains soils (Severson and Tidball 1979). Mercury, selenium, cadmium, and lead were not identified in sediments from the Moreau River at the detection level.

Fish Assemblages

Churchill and Over (1933) and Bailey and Allum (1962) collected 16 fish species from the Moreau River basin (Appendix Table 1). Ten of the fish species reported from the Moreau River basin also have been reported from the adjacent waters of Lake Oahe since 1980 (Riis et al. 1988; Johnson et al. 1991).

Bad River

Sediments

Copper, manganese, and nickel in sediment samples from the Bad River (Appendix Table 11) exceeded the geometric mean for these elements in western U.S. soils (Shacklette and Boerngen 1984) and northern Great Plains soils (Severson and Tidball 1979). Mercury, selenium, lead, and cadmium were not identified in sediments from the Bad River at the detection level.

Fish Assemblages

Nine fish species were historically documented (Churchill and Over 1933; Bailey and Allum 1962) from the Bad River, and an additional 17 species were reported from the Missouri River near the Bad River confluence (Appendix Table 1). Riis et al. (1988) and Johnson et al. (1991) sampled after 1980 and collected 17 of the fish species reported in the Bad River before 1955. The sicklefin chub, reported before 1955, is currently on the state's threatened list, while the pallid sturgeon, documented as present in the 1980's (J. Riis, South Dakota Department of Game, Fish, and Parks, personal communication), is rare and a state and

federal endangered species (Ashton and Dowd 1991).

White River

Sediments

Inorganic element concentrations in all sediment samples from the White River (Appendix Table 11) were near or below the geometric mean for western U.S. soils (Shacklette and Boerngen 1984) and northern Great Plains soils (Severson and Tidball 1979). Mercury, selenium, lead, and cadmium were not identified in White River sediments at the detection level.

Fish Assemblages

Twenty-five fish species were documented in the White River basin before 1955 (Appendix Table 1). All species, with the exception of brown trout and common carp, were considered native to the basin. Twelve of the native species documented in earlier studies have been collected from the White River since 1980 (Johnson et al. 1991); pearl dace, sturgeon chub, and sicklefin chub are currently on the South Dakota threatened or endangered list (Ashton and Dowd 1991). Additionally, finescale dace, listed as state-threatened, have been collected since 1980 (Johnson et al. 1991). Fish reproduction and populations in the White River are probably limited by low plankton production, resulting from extremely high turbidity (South Dakota Department of Natural Resources 1975).

South Dakota suffers from periodic droughts, resulting in lower stream flows that also could reduce the abundance and distribution of fish in streams such as the White River.

Missouri River

Sediments

Arsenic and mercury concentrations were elevated in sediments collected from Foster Bay on the Cheyenne River arm of the Oahe Reservoir in 1984 (Appendix Table 12). Maximum concentrations of mercury were higher than concentrations reported in sediments from the Whitewood Creek, the Belle Fourche River, and the Cheyenne River. Arsenic was higher in Missouri River sediments than in Cheyenne River sediments.

Arsenic concentrations in Missouri River sediments ranged between 1.8 and 9.2 $\mu\text{g/g}$ (Appendix Table 13). Arsenic concentrations in sediments from five of nine Missouri River locations were at

or slightly exceeded the geometric mean of 5.5 $\mu\text{g/g}$ for northern Great Plains soils reported by Shacklette and Boerngen (1984). No mercury concentration in sediment exceeded 1.0 $\mu\text{g/g}$; however, concentrations at 10 of 21 stations sampled exceeded the geometric mean of 0.046 $\mu\text{g/g}$ for northern Great Plains soils.

Lead concentrations in sediments at 3 of 14 Missouri River sites exceeded geometric means reported for western U.S. soils (Shacklette and Boerngen 1984) and northern Great Plains soils (Severson and Tidball 1979). Concentrations of barium, boron, copper, nickel, and zinc were low and below the geometric means reported for northern Great Plains soils (Severson and Tidball 1979).

Selenium concentrations in sediments exceeded the geometric mean of 0.23 $\mu\text{g/g}$ for northern Great Plains soils at 11 of 21 sites sampled (Appendix Table 13). The highest concentrations of selenium in sediments were in lower Lake Francis Case and Lewis and Clark Lake (Phillips et al. 1987). Selenium in these lakes probably originated from local sources, such as marine shale deposits located in watershed soils and along shorelines.

The Missouri River islands, where sediments were collected in 1990 for analyses, are listed by river kilometer (Appendix Table 13). Selenium concentrations in sediments collected from around the islands ranged from less than 0.30 to 0.80 $\mu\text{g/g}$. Selenium and other inorganic chemicals were present at or near background concentrations in sediments collected in the vicinity of the islands.

Selenium is a naturally occurring trace element that is an essential nutrient in small amounts but becomes toxic at higher concentrations. Selenium is toxic at concentrations only slightly above required dietary levels (Ohlendorf and Skorupa 1989). It is highest in soils associated with coal deposits and marine shales. Selenium is easily leached from seleniferous soils by irrigation water or natural precipitation.

Cadmium and selenium were elevated in bluff shale samples collected in 1990. Selenium concentrations in shale samples ranged between 4.79 and 13.60 $\mu\text{g/g}$ with a mean of 7.45 $\mu\text{g/g}$. Normal background concentrations of selenium in shale are about 0.16 $\mu\text{g/g}$ (Eisler 1985b). Maximum selenium concentrations in the marine shales bordering the Missouri River are over 20 times higher than the background concentrations reported by Eisler (1985b).

Cadmium concentrations in shale samples ranged from 1.56 to 9.35 $\mu\text{g/g}$ with a mean of

5.72 $\mu\text{g/g}$. Background cadmium concentrations in soils are 1.0 $\mu\text{g/g}$ or lower (Eisler 1985a). The cadmium concentrations in shale (maximum concentration 9.35 $\mu\text{g/g}$) collected from the Missouri River bluffs were elevated compared with normal soil concentrations. Cadmium in the dry bluffs is biologically unavailable until it moves from the bluffs and enters the aquatic environment. Cadmium may enter and bioaccumulate in food chains under the right conditions. However, the fate of cadmium eroded from the bluffs is not known after it enters the Missouri River.

The shale bluffs bordering the Missouri River in southeastern South Dakota are eroded by wind and wave action. The unweathered shale falls into the water, where it is pulverized by waves, rocks, and ice. The physical alteration of shale may result in the transfer of inorganic contaminants from the shale to river water or sediments. Selenium may be oxidized and modified into a more bioavailable form that can enter local aquatic foods or wash downstream, where it settles out in slack-water areas. These slack-water areas are along stream borders or near islands that are important fish and wildlife habitats. The relocation of selenium from shale bluffs to slack-water areas downstream increases the possibility of aquatic organism exposure.

Birds

In a study by Ohlendorf et al. (1990), percentage moisture in 173 adult bird livers representing 16 different species averaged 70.16%. This percentage moisture in bird livers was used to convert wet weight selenium and mercury concentrations to dry weights for the birds we collected so that mercury and selenium could be compared with concentrations reported in the literature.

Mercury was elevated in the livers of adult double-crested cormorants collected from the Cheyenne River arm of Oahe Reservoir in 1984 (Appendix Table 14). Mercury in adult cormorant livers ranged from 1.90 to 36.00 $\mu\text{g/g}$ wet weight. Mercury concentrations in juvenile cormorant livers were much lower than in adults and ranged between 0.38 and 1.30 $\mu\text{g/g}$. Mercury concentrations in adult cormorants sampled for this study were highly elevated compared with the concentrations reported in the livers of other birds.

Mercury concentrations of 1.1 $\mu\text{g/g}$ wet weight in liver or kidney should be considered as presumptive evidence of an environmental mercury problem (Eisler 1987). Mercury concentrations detected in adult cormorant livers in this study

were within the range reported to be lethal for other birds. Fimreite (1979) reported that 8.3% of 289 domestic chickens (*Gallus gallus*) died after mercury exposure, and 18 $\mu\text{g/g}$ of mercury were detected in livers of the dead birds. Mercury concentrations of 17 to 20 $\mu\text{g/g}$ were detected in the livers of red-tailed hawks (*Buteo jamaicensis*) that died after mercury exposure (Fimreite and Karstad 1971).

Mercury concentrations were higher in fish-eating birds than in other birds that frequented mercury-polluted habitats. Hesse et al. (1975) reported mercury concentrations of 92.4, 49.4, and 38.5 $\mu\text{g/g}$ in livers of double-crested cormorants collected from the Cheyenne River in South Dakota. Mercury in livers of nine other birds they collected from the same area were low and ranged from 0.17 to 0.98 $\mu\text{g/g}$. They attributed the mercury source to past Black Hills mining activities.

Powell (1983) reported a range of mean mercury concentrations between 0.05 and 2.10 $\mu\text{g/g}$ wet weight in the livers of nine different bird species from a control area. He reported a range of mercury values of 0.87 to 11.40 $\mu\text{g/g}$ wet weight in livers of birds from a contaminated area. Fleming (1981) reported that mercury in livers of adult canvasbacks (*Aythya valisineria*) ranged from 0.02 to 0.63 $\mu\text{g/g}$ wet weight. Mercury concentrations in birds sampled for this study were highly elevated compared with the concentrations reported in livers of other birds.

Selenium was elevated in livers of adult double-crested cormorants collected from the Cheyenne River arm of Oahe Reservoir in 1984 (Appendix Table 14). Wet weight selenium concentrations in livers of adult cormorants were higher than in the livers of juveniles, with concentration ranges of 7.20 to 21.00 $\mu\text{g/g}$ and 1.30 to 6.70 $\mu\text{g/g}$, respectively (Appendix Table 14). Selenium concentrations in cormorants from the Cheyenne River arm of Oahe Reservoir were higher than those reported by Ohlendorf et al. (1988) for birds from control areas, but they were lower than concentrations reported in livers of birds from highly contaminated areas.

The mean background selenium concentration in birds from control areas was 8.3 $\mu\text{g/g}$ dry weight in Ohlendorf et al.'s (1988) study. They reported that selenium concentrations in birds from contaminated areas averaged 94.4 $\mu\text{g/g}$ dry weight. Selenium in adult bird livers changed significantly within and between years for birds inhabiting areas of high contamination. They reported little

difference in selenium concentrations in livers between species for adult birds at control sites where levels of selenium in foods were normal.

The higher concentrations of mercury and selenium in livers of our adult birds may have been caused by elevated contaminants in their foods and longer exposure duration. However, presence in juvenile birds demonstrates that selenium and mercury are being accumulated from local foods.

When selenium and mercury are present together in bird tissues, the toxicity of each is reduced (Eisler 1987). The individual toxicity of selenium and mercury in Cheyenne River cormorant livers may have been counteracted by the other element's presence.

Fish Contaminants

Northern pike, walleye, channel catfish, and common carp were collected for inorganic chemical analyses from Foster Bay on the Cheyenne River arm of Oahe Reservoir in 1970-71 and in 1984 (Appendix Tables 15 and 16). Mean mercury concentrations in edible tissue from all fish were much lower in 1984 than in 1970-71.

In 1971, northern pike, walleye, channel catfish, and common carp collected from the upper Cheyenne River arm of Oahe Reservoir, Whitlock Bay, and Oahe Reservoir tailwaters were analyzed for mercury (Appendix Table 15). Mean mercury concentrations were higher in fish from the Cheyenne River arm than in fish from the other two locations. In general, mercury concentrations were highest in northern pike.

Mercury was not detected in composited samples of forage fish collected around Missouri River islands (Appendix Table 17). Selenium was elevated in forage fish, and concentrations in four of five samples exceeded the NCBP 85th percentile dry weight concentration of about 2.8 $\mu\text{g/g}$ (Lowe et al. 1985). Cadmium, chromium, and zinc concentrations in forage fish were similar to the NCBP 85th percentile concentration. Lead was not detected in two forage fish samples, but exceeded the NCBP 85th percentile dry weight concentration of about 1.28 $\mu\text{g/g}$ in three samples.

Background selenium concentrations in fish from contaminant-free water average about 2 $\mu\text{g/g}$ whole-body wet weight (Eisler 1985b). The forage fish in our study were the size that would be selected as food by other fish and some birds. Ohlendorf and Skorupa (1989) cited studies conducted in the western United States showing that selenium pollution of waterbird food generally is

in the range of 5 to 50 $\mu\text{g/g}$ dry weight. Selenium concentrations in forage fish in this study ranged between 2.28 $\mu\text{g/g}$ dry weight (0.41 $\mu\text{g/g}$ wet weight) and 4.82 $\mu\text{g/g}$ dry weight (1.18 $\mu\text{g/g}$ wet weight). The selenium concentrations in Missouri River forage fish are lower than concentrations reported in waterbird foods from contaminated areas. Selenium concentrations in Missouri River forage fish were, based on studies conducted on other species, below dietary levels of concern for waterbirds.

Conclusions

- Arsenic, mercury, and selenium were elevated in Whitewood Creek sediments.
- No fish were present in Gold Run and Whitewood creeks in the vicinity of Lead and Deadwood in 1971. Fish and other aquatic organisms are now present in Whitewood Creek.
- In the Belle Fourche River sediments, arsenic, zinc, manganese, and nickel were elevated.
- In the Cheyenne River sediments, concentrations of arsenic were elevated, and concentrations of barium, boron, manganese, nickel, and zinc were higher than background.
- Concentrations of selenium were elevated in Cheyenne River fish.
- Mercury was higher in fish from Foster Bay on the Cheyenne River arm of Oahe reservoir than in fish from Oahe Reservoir or from the reservoir tailwaters. Mercury concentrations in Foster Bay fish seemed to have declined between 1970-71 and 1984.
- Mercury and selenium in livers of adult cormorants from the Cheyenne River arm of Oahe Reservoir were higher than in livers of juvenile cormorants.
- Mercury in livers of adult cormorants collected from the Cheyenne River arm of Oahe Reservoir was much higher than mercury in livers of cormorants from control areas in other studies.
- Selenium in livers of adult cormorants collected from the Cheyenne River arm of Oahe Reservoir was higher than selenium in livers of cormorants from control areas, but lower than in birds collected from highly contaminated areas in other studies.
- Selenium in sediments was elevated in Gold Run Creek, Cheyenne River, Lake Francis Case, and Lewis and Clark Lake.

Recommendations

- Remediation of areas contaminated or impacted by mine wastes—especially in the northern Black Hills—should continue.
- Selenium is hazardous to fish and wildlife especially when it enters aquatic environments:
 1. Continue to monitor polluted areas. Aquatic habitats where selenium concentrations are elevated enough to cause wildlife health problems should be managed to prevent wildlife exposure. Fish and wildlife management efforts should be conducted on areas where selenium is not a problem, thereby attracting animals to clean sites.
 2. Confine environmental selenium to keep it from spreading. Shale bluffs containing selenium border the Missouri River and Lewis and Clark Lake. The shale sloughs off into the water making selenium available through aquatic foods. Rip-rapping or other bank stabilization techniques on parts of the shoreline would prevent selenium from entering the water.
- Siltation should be reduced by better land management in the watershed.
- Serious consideration should be given to increasing habitat diversity on the Missouri River in South Dakota and other areas throughout the drainage. Improved habitat diversity would be of great value to fish species for all life functions and to many wildlife species, including migratory birds, that use islands and shoal areas for resting and feeding. State and federal agencies should work cooperatively to develop a long-term plan for habitat restoration on the river.
- An intensive fish sampling program should be implemented on the tributary rivers to document current fish assemblages. Only two comprehensive studies of fish species diversity in western Missouri River tributary streams have been conducted, and these were in 1955 or earlier. Lack of current data makes evaluation of tributary fish populations difficult.

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Appendix Table 1. Fish species collected from five western tributaries to the Missouri River in South Dakota before 1955 (Churchill and Over 1933; Bailey and Allum 1962) and after 1980 (Koth and Ford 1980; Riis et al. 1988; Johnson et al. 1991). In 1980, Cheyenne River fish were collected from the upper basin; data for other streams are represented by fish collected from the Missouri River near its confluence with the tributary.^a

Common name ^b	White River		Bad River		Cheyenne River		Moreau River		Grand River	
	1955	1980	1955	1980	1955	1980	1955	1980	1955	1980
Pallid sturgeon	?		?	X	?	?	?	?	X	?
Shovelnose sturgeon	?	X	X	X	?	X	?	X	X	X
Paddlefish	?	X	?	?	?	?	?	?	?	?
Shortnose gar	X	X	X	X	X	X	X	X	X	X
Goodeye	X	X	X	X	X	X	X	X	X	X
Brook trout					X					
Brown trout	X				X	X	X			X
Rainbow trout					X	X	X			X
Bluntnose minnow				X		X	X		X	X
Creek chub	X	X	X	X	X				X	
Common carp		X	X	X	X	X	X		X	X
Fathead minnow	X	X	X	X	X	X	X	X	X	X
Finescale dace		X			X					
Flathead chub	X		X		X		X		X	
Golden shiner				X	X	X	X			X
Lake chub					X					
Longnose dace	X		X		X		X			
Pearl dace	X									
Plains minnow	X		X		X		X		X	
Sand shiner	X	X	X		X	X	X	X	X	X
Silverband shiner	X									
Silvery minnow	X	X	X				X		X	
Sicklefin chub	X		X						X	
Stoneroller	X									
Sturgeon chub	X				X				X	
Blue sucker	X	X		X		X	X			X
Longnose sucker					X					
Mountain sucker					X					
River carpsucker	?	X	X	X	X	X	X	X	X	X
Shorthead redhorse	X	X	X	X	X	X	X	X	X	X
White sucker	X	X		X	X	X	X	X	X	X
Black bullhead	X	X	X	X	X	X	X	X	X	X
Blue catfish	X				X					
Channel catfish	X	X	X	X	X	X	X	X	X	X
Stonecat	X		X		X		X		X	
Burbot		X		X		X	X		X	X
Plains killifish					X					
Black crappie	?	X	X	X		X	X		X	X
Bluegill	X	X		X					X	
Green sunfish	X		X		X		X		X	
Largemouth bass		X		X	X	X	X		X	X
Orangespotted sunfish	?	X	X	X	X	X	X		X	X
Pumpkinseed	X		X						X	
White crappie	?	X	X	X		X	X		X	X
Sauger	?	X	X	X	?	X	?	X	X	X
Walleye	?	X	X	X	X	X	?	X	X	X
Yellow perch	?	X	X	X	X	X	X	X	X	X
Freshwater drum	?	X	X	X	?	X	?	X	X	X

^a? = not collected in pre-1955 work, but suspected to have at least seasonally used the drainage.

^bScientific names listed in Appendix Table 5.

Appendix Table 2. Selected hydrologic and basin values for the Grand, Moreau, Cheyenne, Bad, and White rivers, South Dakota.

River	Years of data	Maximum flow (cfs)	Minimum flow (cfs)	Mean flow (cfs)
Grand: Reach from confluence Cheyenne River to confluence Firesteel Creek	34	31,000	0	231
Grand: At Shadehill Reservoir	49	58,000	0	111
Moreau: Reach from confluence North and South Forks to confluence Thunder Butte Creek	49	26,000	0	131
Moreau: Reach from confluence Thunder Butte Creek to Whitehorse, South Dakota	38	27,000	0	209
Cheyenne: Reach from confluence Belle Fourche River to confluence Cherry Creek	30	41,000	0	610
Cheyenne: Reach from confluence Cherry Creek to Lake Oahe	32	55,900	0	800
Bad: Gage station near Midland, South Dakota	47	29,400	0	N/A
Bad: Gage station near Ft. Pierre, South Dakota	64	43,800	0	148
White: Reach from South Dakota-Nebraska line to confluence Blacktail Creek	49	5,200	0	53
White: Reach from Bear-in-the-Lodge Creek to confluence Little White River	50	21,700	0	267
White: Reach from confluence Little White River to confluence Missouri River	66	51,900	0	524

Appendix Table 3. Site collection locations for fish and sediment samples Cheyenne River drainage. Data from Greene et al. (1990). Site locations are for data in Appendix Tables 8 and 10.

Site	Location	Media
1	Cheyenne River near Edgemont, South Dakota	Fish
2	Cheyenne River near Hot Springs, South Dakota	Sediment
3	Horsehead Creek at Oelrichs, South Dakota	Sediment
4	Angustura Reservoir near Hot Springs, South Dakota	Sediment
6	Angustura Canal near Hot Springs, South Dakota	Sediment
7	Fall River at mouth near Hot Springs, South Dakota	Sediment
8	Cheyenne River upstream from Buffalo Gap, South Dakota	Sediment
10	Iron Draw near Buffalo Gap, South Dakota	Sediment
12	Cheyenne River near Custer County 656 Bridge	Fish
13	Cottonwood Creek near Buffalo Gap, South Dakota	Sediment
14	French Creek near Fairburn, South Dakota	Sediment and fish

Appendix Table 4. Site collection locations for fish and sediment samples, Belle Fourche River drainage. Data from Roddy et al. (1991). Site locations are for Appendix Tables 6 and 7.

Site	Location	Description	Media
2	Belle Fourche River upstream from Belle Fourche	Belle Fourche River upstream from Belle Fourche	Fish
3	Redwater River above Willow Creek at Belle Fourche	Redwater River—a major tributary to the Belle Fourche River	Sediment
4	Crow Creek near Belle Fourche	Background site on tributary to Belle Fourche River	Sediment
5	Inlet canal near Belle Fourche	Site is downstream from Crow Creek and upstream from Belle Fourche Reservoir	Sediment
6	Belle Fourche Reservoir near Belle Fourche	Submerged channel of Owl Creek in the Belle Fourche Reservoir	Sediment
7	Irrigation canal near Fruitdale	Irrigation canal leading from Belle Fourche Reservoir	Sediment
12	Horse Creek above Vale	Creek receives irrigation return flows	Sediment and fish
18	Belle Fourche River near Sturgis	Belle Fourche River downstream from irrigation return flow	Sediment and fish
19	Sulphur Creek near Newell	Background site	Sediment

Appendix Table 5. Common and scientific names of fishes in this report.

Common name	Scientific name
Pallid sturgeon	<i>Scaphirhynchus albus</i>
Shovelnose sturgeon	<i>S. platyrhynchus</i>
Paddlefish	<i>Polyodon spathula</i>
Shortnose gar	<i>Lepisosteus platostomus</i>
Goldeye	<i>Hiodon alosoides</i>
Rainbow trout	<i>Oncorhynchus mykiss</i>
Brown trout	<i>Salmo trutta</i>
Brook trout	<i>Salvelinus fontinalis</i>
Central stoneroller	<i>Camptostoma anomalum</i>
Lake chub	<i>Couesius plumbeus</i>
Red shiner	<i>Cyprinella lutrensis</i>
Spotfin shiner	<i>C. spiloptera</i>
Common carp	<i>Cyprinus carpio</i>
Mississippi silvery minnow	<i>Hybognathus nuchalis</i>
Plains minnow	<i>H. placitus</i>
Sturgeon chub	<i>Macrhybopsis gelida</i>
Sicklefin chub	<i>M. meeki</i>
Pearl dace	<i>Margariscus margarita</i>
Golden shiner	<i>Notemigonus crysoleucas</i>
Emerald shiner	<i>Notropis atherinoides</i>
Silverband shiner	<i>N. shumardi</i>
Sand shiner	<i>N. stramineus</i>
Finescale dace	<i>Phoxinus neogaeus</i>
Bluntnose minnow	<i>Pimephales notatus</i>
Fathead minnow	<i>P. promelas</i>
Flathead chub	<i>Platygobio gracilis</i>
Longnose dace	<i>Rhinichthys cataractae</i>
Creek chub	<i>Semotilus atromaculatus</i>
River carpsucker	<i>Carpoides carpio</i>
Longnose sucker	<i>Catostomus catostomus</i>
White sucker	<i>C. commersoni</i>
Mountain sucker	<i>C. platyrhynchus</i>
Blue sucker	<i>Cycleptus elongatus</i>
Shorthead redhorse	<i>Moxostoma macrolepidotum</i>
Black bullhead	<i>Ameiurus melas</i>
Blue catfish	<i>Ictalurus furcatus</i>
Channel catfish	<i>I. punctatus</i>
Stonecat	<i>Noturus flavus</i>
Burbot	<i>Lota lota</i>
Plains killifish	<i>Fundulus zebrinus</i>
Green sunfish	<i>Lepomis cyanellus</i>
Pumpkinseed	<i>L. gibbosus</i>
Orangespotted sunfish	<i>L. humilis</i>
Bluegill	<i>L. macrochirus</i>
Largemouth bass	<i>Micropterus salmoides</i>
White crappie	<i>Pomoxis annularis</i>

Appendix Table 5. Continued.

Common name	Scientific name
Black crappie	<i>P. nigromaculatus</i>
Yellow perch	<i>Perca flavescens</i>
Sauger	<i>Stizostedion canadense</i>
Walleye	<i>S. vitreum</i>
Freshwater drum	<i>Aplodinotus grunniens</i>

**Appendix Table 6. Concentrations ($\mu\text{g/g}$ dry weight) of elements in Belle Fourche River drainage sediments. Data from Roddy et al. (1991).
Site locations are identified in Appendix Table 4.**

Site	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Zinc
3	7.50	440.00	1.60	<2.00	21.00	10.00	10.00	360.00	<0.02	<2.00	8.00	0.90	33.00
3	6.10	380.00	1.10	<2.00	32.00	11.00	11.00	390.00	<0.02	<2.00	13.00	1.00	35.00
4	25.00	110.00	3.60	<2.00	35.00	21.00	14.00	1200.00	<0.02	9.00	43.00	1.30	150.00
4	16.00	91.00	5.60	<2.00	55.00	25.00	12.00	770.00	0.02	5.00	36.00	1.20	110.00
5	16.00	720.00	0.60	<2.00	22.00	12.00	21.00	1800.00	<0.02	2.00	35.00	0.90	93.00
5	8.80	610.00	1.10	<2.00	43.00	18.00	18.00	1700.00	<0.02	<2.00	36.00	0.80	91.00
6	8.60	480.00	1.70	<2.00	39.00	15.00	16.00	590.00	0.02	<2.00	26.00	0.70	74.00
6	9.20	460.00	1.70	<2.00	40.00	16.00	15.00	610.00	<0.02	<2.00	27.00	0.80	75.00
6	7.80	480.00	1.70	<2.00	39.00	17.00	14.00	570.00	<0.02	<2.00	26.00	0.70	72.00
6	6.00	530.00	1.10	<2.00	36.00	14.00	13.00	580.00	<0.02	<2.00	19.00	0.60	59.00
6	5.90	530.00	0.90	<2.00	38.00	13.00	14.00	620.00	<0.02	<2.00	26.00	0.60	62.00
6	5.90	530.00	0.90	<2.00	36.00	13.00	13.00	580.00	<0.20	<2.00	21.00	0.60	60.00
7	59.00	820.00	1.40	<2.00	41.00	15.00	47.00	320.00	0.02	2.00	28.00	1.00	78.00
7	30.00	590.00	0.70	<2.00	54.00	16.00	13.00	220.00	<0.02	<2.00	27.00	0.90	72.00
12	39.00	1670.00	3.10	<2.00	46.00	21.00	18.00	1490.00	0.06	5.00	48.00	3.50	124.00
12	12.00	1140.00	2.90	<2.00	62.00	19.00	18.00	686.00	0.12	<2.00	37.00	2.80	104.00
18	180.00	800.00	2.40	<2.00	40.00	19.00	15.00	1310.00	0.10	3.00	33.00	1.70	89.00
18	370.00	927.00	2.90	<2.00	61.00	31.00	19.00	1770.00	0.20	<2.00	41.00	2.20	112.00
19	19.00	220.00	2.20	<2.00	54.00	22.00	19.00	1100.00	0.02	2.00	36.00	0.90	95.00
19	11.00	160.00	2.10	<2.00	62.00	21.00	19.00	730.00	0.02	<2.00	33.00	0.70	82.00

Appendix Table 7. Concentrations ($\mu\text{g/g}$ dry weight) of elements detected in fish from the Belle Fourche River drainage, 1988. Data from Roddy et al. (1991). Site locations are identified in Appendix Table 4.

Site	Species	Percent moisture	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Zinc
2	Flathead chub (3 fish)	71.10	0.60	7.30	2.00	0.30	2.00	3.30	<4.00	56.20	0.44	<1.00	2.00	2.80	92.40
2	Flathead chub	73.20	<0.10	3.50	<2.00	<0.40	<1.00	2.10	<4.00	16.00	0.08	<1.00	<3.00	2.40	99.40
2	Flathead chub (3 fish)	68.90	<0.20	4.00	<2.00	0.20	<1.00	4.40	<4.00	11.00	0.04	<1.00	3.00	2.00	88.00
2	Flathead chub	71.70	<0.10	2.10	<2.00	<0.40	<1.00	1.00	<4.00	4.60	0.05	<1.00	<3.00	1.50	73.50
2	Flathead chub	67.50	<0.20	2.30	<2.00	0.20	0.87	2.70	<0.90	3.20	0.05	<0.10	<0.80	1.50	71.20
2	Flathead chub	75.70	<0.20	5.40	<2.00	0.60	1.70	2.60	<0.90	45.60	0.11	0.20	2.00	2.30	121.00
2	Flathead chub (2 fish)	72.80	<0.20	3.70	<2.00	0.30	2.00	3.80	<4.00	23.60	0.06	<1.00	1.00	1.90	97.00
2	Shorthead redhorse (3 fish)	70.40	<0.20	6.90	<2.00	0.40	<1.00	3.30	<4.00	56.90	0.09	<1.00	<1.00	2.60	123.00
2	Shorthead redhorse (3 fish)	72.60	<0.20	4.70	3.00	0.30	<1.00	3.00	<4.00	51.80	0.17	<1.00	<1.00	2.50	101.00
2	Shorthead redhorse (3 fish)	71.40	<0.20	5.60	<2.00	0.50	<1.00	3.80	<4.00	73.80	0.13	<1.00	1.00	3.00	120.00
2	Shorthead redhorse	72.20	0.41	6.20	10.00	0.50	2.00	2.10	<4.00	44.70	0.14	<1.00	<3.00	2.70	101.00
2	Shorthead redhorse (3 fish)	71.20	<0.20	3.90	<2.00	0.40	2.00	3.20	<4.00	53.40	0.12	<1.00	2.00	2.40	127.00
2	Shorthead redhorse	71.60	0.20	7.10	12.00	<0.40	2.00	1.90	<4.00	73.60	0.11	<1.00	3.00	2.40	85.70
2	Shorthead redhorse	72.40	0.20	4.30	7.40	<0.40	3.60	1.50	<4.00	32.00	0.16	<1.00	<3.00	2.60	88.50
2	Shorthead redhorse	75.20	<0.20	7.30	3.00	0.49	1.40	3.51	<0.60	85.80	0.17	0.61	2.80	3.40	105.00
2	Shorthead redhorse	74.50	<0.20	6.50	<2.00	0.56	1.40	2.50	<0.90	61.30	0.28	0.30	2.00	2.90	89.40
2	Shorthead redhorse	72.00	0.20	4.90	16.00	0.60	3.00	2.30	<4.00	63.50	0.15	<1.00	<3.00	2.40	86.50
2	Shorthead redhorse	74.50	<0.20	3.80	<2.00	0.26	1.80	2.60	<0.60	50.60	0.40	0.20	1.80	2.20	92.10
2	Shorthead redhorse	75.90	<0.20	4.10	<2.00	0.32	1.50	2.50	<0.90	51.50	0.41	<0.10	<0.80	2.10	86.10
2	Shorthead redhorse	73.30	<0.20	4.50	<2.00	0.39	0.70	2.10	<1.00	69.90	0.36	0.20	<1.00	2.60	83.50
2	Shorthead redhorse	74.50	0.20	4.20	4.00	1.50	<1.00	2.70	<4.00	48.00	0.26	<1.00	<3.00	2.80	96.40
12	Flathead chub (3 fish)	69.00	0.30	16.00	<2.00	<0.02	1.80	2.96	0.50	55.40	0.09	<1.00	1.30	3.60	72.30
12	Flathead chub	72.90	<0.10	4.40	<2.00	<0.40	<1.00	2.00	<4.00	8.80	0.12	<1.00	<3.00	3.60	86.80
12	Flathead chub	76.00	<0.20	5.90	<2.00	0.10	1.80	2.50	<0.90	15.70	0.15	<0.10	0.90	4.10	92.50
12	Flathead chub	74.30	0.20	6.50	<2.00	<0.40	<1.00	2.10	<4.00	16.00	0.28	<1.00	<3.00	4.30	104.00
12	Flathead chub	75.20	<0.20	2.40	<2.00	0.20	1.60	2.40	<0.90	9.68	0.16	0.71	3.70	4.60	85.10
12	Flathead chub (3 fish)	71.30	<0.20	3.60	<2.00	0.02	0.33	2.25	<0.40	11.70	0.08	<1.00	0.20	3.00	78.10
12	Flathead chub	67.80	0.30	3.80	<2.00	<0.02	0.60	2.00	<0.40	17.50	0.06	<1.00	0.35	3.80	84.50
12	Flathead chub	68.70	<0.20	2.10	<2.00	0.04	0.20	2.49	<0.40	10.50	0.24	<1.00	0.10	5.10	72.90
12	Flathead chub	72.10	0.10	4.70	<2.00	<0.40	2.00	2.20	<4.00	15.00	0.20	<1.00	<3.00	4.10	90.20

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Appendix Table 7. Continued.

Site	Species	Percent moisture	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Zinc
12	Flathead chub	69.50	<0.20	3.50	<2.00	0.03	0.56	2.45	0.40	27.30	0.09	<1.00	0.48	3.30	78.70
12	Shorthead redhorse	71.60	<0.20	7.20	6.00	<0.20	1.90	2.25	<0.40	65.00	0.10	<1.00	0.96	2.70	82.60
12	Shorthead redhorse	67.80	0.20	4.50	3.00	<0.02	0.41	2.28	<0.40	42.20	0.10	<1.00	0.30	1.80	64.30
12	Shorthead redhorse	66.60	<0.20	5.50	3.00	<0.02	0.30	2.10	<0.40	35.00	0.05	<1.00	0.20	2.90	58.30
12	Shorthead redhorse	71.40	0.30	4.80	15.00	<0.40	2.00	1.50	<4.00	38.10	0.16	<1.00	<3.00	2.80	79.00
12	Shorthead redhorse	73.70	0.37	6.80	16.00	<0.40	2.00	1.80	<4.00	34.00	0.21	<1.00	<3.00	2.50	67.00
12	Shorthead redhorse	70.50	0.20	4.30	17.00	<0.40	2.00	1.40	<4.00	48.80	0.16	<1.00	<3.00	2.50	67.10
12	Shorthead redhorse	69.70	<0.20	6.70	3.00	<0.02	0.74	2.32	<0.40	33.60	0.17	<1.00	0.30	2.40	56.80
12	Shorthead redhorse	69.30	0.20	7.70	3.00	0.05	1.40	2.71	<0.40	62.40	0.19	<1.00	0.96	3.00	56.60
12	Shorthead redhorse	72.30	<0.20	9.40	<2.00	0.10	2.60	2.40	<1.00	44.30	0.41	0.39	2.00	2.50	68.00
12	Shorthead redhorse	69.50	0.30	5.40	16.00	<0.40	3.00	1.70	<4.00	35.00	0.23	<1.00	<3.00	2.70	60.20
12	Shorthead redhorse	69.60	<0.20	3.30	3.00	<0.02	0.35	2.10	<0.40	25.80	0.18	<1.00	<0.10	2.10	63.00
12	Shorthead redhorse	71.10	0.60	9.40	<2.00	0.10	3.90	3.30	<1.00	54.30	0.32	0.20	2.90	2.90	69.40
12	Shorthead redhorse	72.40	<0.20	5.30	<2.00	0.20	1.30	2.70	<0.90	41.40	0.41	0.20	0.90	2.70	72.80
12	Shorthead redhorse	68.40	0.20	4.60	<2.00	0.13	<0.10	2.00	<0.50	38.10	0.66	<1.00	<0.10	2.50	58.60
12	Shorthead redhorse	71.00	<0.20	6.30	<2.00	0.10	1.40	2.59	<0.50	42.90	0.30	1.00	5.20	2.00	67.90
12	Shorthead redhorse	71.10	<4.90	84.00	<2.00	0.20	1.80	3.50	1.00	56.60	0.33	0.35	2.00	3.90	64.90
12	Shorthead redhorse	71.60	0.30	9.50	<2.00	0.20	1.80	3.10	2.00	40.00	0.39	0.35	2.00	2.40	67.00
12	Shorthead redhorse	77.00	1.20	35.00	4.00	<0.40	2.00	4.90	<4.00	67.80	0.70	<1.00	<3.00	3.10	75.60
12	Shorthead redhorse	69.30	2.20	20.30	<2.00	0.11	1.20	3.09	<0.50	75.40	0.21	<1.00	2.40	2.80	61.80
12	Shorthead redhorse	73.20	0.40	5.90	<2.00	0.15	0.83	3.27	<0.40	35.60	0.44	<1.00	2.40	2.90	60.50
18	Common carp	79.90	2.00	3.50	<2.00	0.11	0.56	6.12	<0.40	24.30	0.32	<1.00	0.63	3.90	358.00
18	Common carp	78.60	3.20	4.90	<2.00	0.09	0.71	6.06	<0.40	35.30	0.35	<1.00	0.87	3.20	255.00
18	Common carp	78.10	7.60	4.90	<2.00	0.34	0.81	5.96	<0.40	18.70	0.69	<1.00	0.75	4.60	601.00
18	Common carp	76.10	3.40	3.40	<2.00	0.14	2.80	5.21	<0.40	11.30	0.98	<1.00	1.40	5.30	355.00
18	Common carp	75.10	3.80	4.20	<2.00	0.23	1.50	4.85	<0.40	15.60	0.57	<1.00	0.71	4.80	359.00
18	Common carp	72.50	3.50	8.10	<2.00	0.44	2.80	4.76	<0.40	26.10	0.89	<1.00	1.50	4.70	154.00
18	Shorthead redhorse	69.20	1.30	4.90	<2.00	0.20	1.90	2.00	<1.00	79.80	0.39	0.92	4.50	3.40	61.10
18	Shorthead redhorse	70.30	3.00	5.10	<2.00	0.12	0.49	2.53	<0.50	47.40	0.58	<1.00	0.97	3.60	66.40
18	Shorthead redhorse	66.60	4.30	6.00	2.00	0.06	0.30	2.45	<0.50	70.90	0.35	<1.00	0.30	2.90	56.30
18	Shorthead redhorse	70.40	3.90	4.90	<2.00	0.06	0.39	2.67	<0.50	52.90	0.41	<1.00	0.45	3.80	57.60
18	Shorthead redhorse	71.50	2.20	3.40	4.00	<0.40	<1.00	1.70	<4.00	35.00	0.96	<1.00	<3.00	3.70	46.90
18	Shorthead redhorse	67.80	2.40	8.00	<2.00	0.20	2.40	2.50	<0.90	49.40	0.78	0.55	2.80	2.80	60.30
18	Shorthead redhorse	69.70	3.20	6.70	<2.00	0.20	2.80	2.30	<0.80	73.60	0.66	0.50	2.70	3.50	58.40
18	Shorthead redhorse	69.40	1.40	9.30	<2.00	<0.40	<1.00	1.80	<4.00	33.00	0.83	<1.00	<3.00	3.40	53.00
18	Shorthead redhorse	67.40	1.80	4.60	<2.00	0.20	2.00	2.20	<0.90	44.00	0.67	0.89	3.30	2.80	56.90
18	Shorthead redhorse	70.60	2.50	4.00	<2.00	<0.30	2.00	2.00	<4.00	33.00	0.75	<1.00	<2.00	3.80	50.00
18	Shorthead redhorse	69.10	2.20	8.40	<2.00	0.12	2.60	2.89	<0.50	72.80	0.91	<1.00	0.75	3.30	64.50
18	Shorthead redhorse	67.20	1.30	5.20	<3.00	0.40	2.10	3.40	<1.00	28.10	0.71	0.97	1.00	2.90	52.90
18	Shorthead redhorse	67.90	2.20	3.10	<2.00	0.17	1.10	2.36	<0.50	26.40	0.85	<1.00	0.30	3.10	50.90

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Appendix Table 8. Concentrations ($\mu\text{g/g}$ dry weight) of elements in 62- μm fraction of Cheyenne River drainage sediments, 1988. Data from Greene et al. (1990). Site locations are identified in Appendix Table 3.

Site	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Zinc
2	7.60	700.00		<2.00	22.00	9.00	12.00	1100.00	<0.02	<2.00	15.00	1.00	49.00
	6.60	480.00		<2.00	20.00	7.00	12.00	780.00	<0.02	<2.00	9.00	0.60	39.00
	11.00	510.00		<2.00	23.00	8.00	12.00	1300.00	<0.02	<2.00	15.00	0.90	49.00
3	8.60	720.00	5.50	<2.00	64.00	23.00	55.00	470.00	0.04	<2.00	26.00	1.00	96.00
4	7.20	440.00	2.10	<2.00	85.00	26.00	23.00	360.00	0.04	<2.00	26.00	1.00	110.00
6	6.20	400.00	2.10	<2.00	47.00	19.00	28.00	730.00	<0.02	<2.00	24.00	2.10	67.00
7	12.00	760.00	1.20	<2.00	50.00	20.00	18.00	710.00	0.02	<2.00	19.00	0.90	76.00
8	13.00	720.00	1.80	2.00	72.00	28.00	18.00	770.00	0.04	4.00	35.00	4.30	120.00
10	8.90	930.00		<2.00	57.00	21.00	18.00	860.00	0.04	<2.00	23.00	1.60	90.00
13	15.00	150.00	7.30	<2.00	67.00	28.00	18.00	3400.00	0.04	<2.00	31.00	14.00	140.00
14	6.50	1200.00	1.40	<2.00	35.00	16.00	17.00	560.00	0.02	<2.00	15.00	0.60	58.00

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Appendix Table 9. Soil element concentrations from the United States. Except as noted, concentrations are geometric means in $\mu\text{g/g}$. One percent equals 10,000 $\mu\text{g/g}$. Table adapted from Allen (1991).

Element	Western U.S. soils ^a	Northern Great Plains soils ^b
Aluminum	5.80%	5.60%
Antimony	0.47	NA
Arsenic	5.50	7.10
Barium	580.00	1,100.00
Beryllium	0.68	1.60
Boron	23.00	41.00
Cadmium	NA	NA
Chromium	41.00	45.00
Copper	21.00	19.00
Iron	2.10%	2.10%
Lead	17.00	16.00
Magnesium	0.74%	0.66%
Manganese	380.00	460.00
Mercury	0.046	0.023
Molybdenum	0.85	3.80
Nickel	15.00	18.00
Selenium	0.23	0.45
Strontium	200.00	NA
Tin	0.90	160.00
Vanadium	70.00	54.00
Zinc	55.00	63.00

^a Shacklette and Boerngen 1984.

^b Severson and Tidball 1979.

Appendix Table 10. Concentrations ($\mu\text{g/g}$ dry weight) of elements detected in whole-body fish from the Cheyenne River drainage, South Dakota, 1988. Data from Greene et al. (1990). Site locations are identified in Appendix Table 3.

Site	Species	Percent													
		moisture	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nikel	Selenium	Zinc
1	Common carp	80.30	0.50	4.80	<3.00	0.48	<0.20	8.90	<0.50	47.10	0.19	0.42	0.90	2.70	277.00
1	Common carp	78.30	<0.20	9.20	<3.00	0.30	2.00	5.90	<4.00	50.90	0.23	<1.00	<1.00	3.20	289.00
1	Common carp	78.70	<0.20	6.60	<3.00	0.20	<1.00	6.40	<4.00	66.40	0.20	<1.00	<1.00	2.40	273.00
1	Common carp	79.50	<0.20	5.40	<3.00	0.40	<1.00	4.80	<4.00	34.20	0.21	<1.00	<1.00	2.80	283.00
1	Flathead chub	76.90	0.10	3.60	<3.00	<0.60	3.00	2.80	<5.00	33.70	0.22	<1.00	<2.00	5.00	133.00
1	Flathead chub	75.00	<0.20	4.10	<3.00	0.39	0.84	3.03	<0.50	34.40	0.15	0.20	5.70	3.80	129.00
1	Flathead chub	74.30	<0.20	3.90	3.00	0.20	<1.00	2.90	<4.00	12.00	0.16	<1.00	<1.00	3.10	94.20
1	Flathead chub	71.90	0.30	6.90	<3.00	<0.20	<1.00	2.40	<4.00	64.10	0.11	<1.00	<1.00	3.00	122.00
1	Flathead chub	72.10	0.30	14.50	<3.00	<0.30	4.20	3.20	<6.00	131.00	0.09	3.00	18.00	2.10	99.10
12	Common carp	77.40	0.50	9.50	3.00	0.17	1.10	5.51	<0.50	48.70	0.12	<1.00	0.70	5.20	266.00
12	Common carp	77.80	0.10	3.20	<3.00	0.14	0.87	4.60	<0.40	27.80	0.09	<1.00	0.72	6.60	219.00
12	Common carp	78.30	0.30	3.80	<3.00	0.12	1.80	6.00	<0.40	23.70	0.11	<1.00	0.97	6.40	212.00
12	Common carp	78.20	0.20	3.40	<3.00	0.15	1.10	5.32	<0.50	23.10	0.14	<1.00	0.91	5.50	288.00
12	Common carp	77.00	0.53	9.20	3.00	0.15	1.80	4.73	<0.50	42.80	0.09	<1.00	1.10	5.40	225.00
12	Common carp	77.00	0.40	14.50	3.00	0.11	1.20	4.89	<0.40	43.90	0.14	<1.00	0.69	5.90	222.00
12	Common carp	76.40	<0.20	3.80	<3.00	0.10	<0.10	3.97	<0.50	21.70	0.10	0.10	<0.30	5.20	222.00
12	Common carp	78.00	0.30	8.10	<3.00	0.18	2.00	5.48	<0.40	36.60	0.23	<1.00	1.10	8.00	391.00
12	Common carp	75.90	<0.20	2.00	<3.00	0.10	<0.60	1.90	<0.50	13.00	0.31	0.10	<0.40	3.60	101.00
12	Common carp	76.40	<0.20	1.10	<3.00	<0.50	3.00	4.50	<5.00	6.40	0.29	<1.00	<2.00	7.70	234.00
12	Common carp	75.40	0.30	8.00	<3.00	<0.60	<2.00	5.40	<5.00	14.00	0.92	1.00	<2.00	8.00	274.00
12	Common carp	75.50	0.65	10.60	<3.00	<0.60	<2.00	6.70	<5.00	6.70	0.25	<1.00	<5.00	6.90	266.00
12	Common carp	76.50	0.30	4.90	<3.00	<0.60	2.00	4.80	<5.00	20.00	0.46	<1.00	<2.00	7.80	277.00
12	Common carp	77.10	0.34	13.30	3.00	0.23	2.70	5.98	<0.50	37.90	0.53	<1.00	1.60	10.00	197.00
12	Shorthead redhorse	69.20	0.20	6.40	<3.00	<0.60	4.00	2.30	<6.00	73.20	0.13	<1.00	<2.00	5.40	69.00
12	Shorthead redhorse	70.70	0.31	5.40	<3.00	<0.50	3.00	1.80	<5.00	60.50	0.14	<1.00	<2.00	5.90	64.80
12	Shorthead redhorse	69.90	0.20	7.10	<3.00	<0.60	5.00	2.30	<6.00	89.30	0.14	<1.00	7.40	5.80	67.90
12	Shorthead redhorse	72.40	<0.10	6.40	<3.00	0.05	3.20	2.75	<0.50	82.70	0.14	<1.00	3.20	5.20	84.10
12	Shorthead redhorse	72.90	0.30	4.50	<3.00	0.04	0.56	3.74	<0.50	60.50	0.14	<1.00	1.00	4.10	79.50
12	Shorthead redhorse	72.90	0.20	4.60	3.00	0.05	1.40	2.65	<0.50	63.80	0.19	<1.00	0.70	5.00	81.50
12	Shorthead redhorse	69.70	<0.10	4.40	3.00	<0.06	4.20	2.63	<0.50	57.90	0.14	2.00	8.70	5.90	71.20
12	Shorthead redhorse	73.20	0.10	10.00	3.00	0.04	0.57	2.94	<0.50	63.20	0.14	<1.00	0.40	4.40	70.90
12	Shorthead redhorse	70.20	<0.20	5.40	<2.00	0.10	1.60	2.30	<0.50	63.10	0.17	<0.10	0.80	5.50	65.80
12	Shorthead redhorse	71.10	0.10	5.00	<3.00	<0.60	2.00	2.10	<5.00	47.80	0.18	<1.00	5.00	5.10	58.10
12	Shorthead redhorse	69.30	0.20	5.00	3.00	0.10	3.00	2.86	<0.50	57.20	0.21	<0.10	1.50	5.20	64.30
12	Shorthead redhorse	68.30	0.30	142.00	4.00	0.18	1.40	2.30	<0.50	82.70	0.19	<0.10	1.70	4.70	59.60
12	Shorthead redhorse	72.50	0.10	4.30	<3.00	0.07	1.40	6.74	<0.50	38.20	0.37	<1.00	1.70	3.40	72.90
12	Shorthead redhorse	71.90	0.60	8.60	3.00	0.20	1.50	3.00	<0.70	97.00	0.47	0.20	1.00	5.10	68.90
12	Shorthead redhorse	67.20	0.34	11.30	<3.00	0.13	3.40	2.59	<0.50	94.90	0.25	1.00	5.40	3.80	53.90

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Appendix Table 10. Continued.

Site	Species	Percent moisture	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nikel	Selenium	Zinc
12	Shorthead redhorse	73.10	0.67	161.00	<3.00	0.11	4.60	3.63	<0.50	89.20	0.37	<1.00	3.40	5.80	64.80
12	Shorthead redhorse	68.30	0.97	11.10	<3.00	0.09	5.70	2.99	<0.50	65.10	0.30	2.00	11.00	4.70	57.10
14	Common carp	76.10	0.40	17.20	<3.00	0.17	0.30	5.10	<0.50	23.60	0.16	<0.10	0.60	5.60	307.00
14	Common carp	72.80	<0.20	4.80	<3.00	0.24	<0.10	3.69	<0.50	14.70	0.30	0.31	<0.30	3.50	345.00
14	Common carp	71.50	0.20	7.60	<3.00	0.17	2.20	4.49	<0.50	15.50	0.21	0.10	0.90	4.90	312.00
14	Common carp	79.00	0.31	8.00	4.00	0.09	1.30	5.59	<0.50	19.60	0.16	<1.00	0.83	5.30	401.00
14	Common carp	79.50	0.79	18.00	<3.00	0.40	1.60	5.98	0.60	36.30	0.48	<1.00	1.00	6.60	401.00
14	Common carp	82.80	0.55	12.80	<3.00	0.61	3.40	7.31	0.70	25.90	0.75	<1.00	1.70	6.60	248.00
14	Flathead chub	69.80	2.30	24.80	<3.00	0.10	0.62	3.00	1.00	55.10	0.08	4.00	0.40	3.90	88.50
14	Flathead chub	67.80	1.60	20.30	<3.00	0.10	2.30	2.70	0.70	45.60	0.11	2.30	1.20	3.30	93.20
14	Flathead chub	74.10	0.62	10.30	<3.00	<0.60	3.00	1.60	<5.00	15.00	0.17	<1.00	4.00	4.00	84.70
14	Flathead chub	71.50	1.80	28.20	<3.00	<0.60	6.00	3.10	<6.00	48.70	0.12	<1.00	3.00	4.10	93.40
14	Shorthead redhorse	70.30	0.10	23.80	<2.00	<0.04	4.20	2.74	<0.50	51.30	0.13	<1.00	2.40	4.10	78.60
14	Shorthead redhorse	70.30	<0.10	7.00	<3.00	<0.50	3.00	2.00	<5.00	47.30	0.22	<1.00	<2.00	5.30	71.00
14	Shorthead redhorse	70.90	0.30	9.80	<3.00	<0.60	2.00	2.20	<5.00	56.70	0.22	<1.00	2.00	4.30	67.60
14	Shorthead redhorse	71.20	0.10	9.50	3.00	<0.40	<1.00	2.60	<4.00	40.00	0.27	<1.00	<3.00	4.60	82.00
14	Shorthead redhorse	71.10	<0.10	12.90	<3.00	<0.60	2.00	2.00	<5.00	52.10	0.22	<1.00	3.00	3.70	77.50
14	Shorthead redhorse	70.20	0.30	11.30	3.00	0.28	2.40	2.80	<0.50	41.10	0.35	1.70	5.10	4.50	82.00
14	Shorthead redhorse	73.00	<0.10	7.50	<3.00	0.07	1.80	2.87	<0.50	71.70	0.13	<1.00	1.70	6.30	84.50
14	Shorthead redhorse	67.50	<0.10	2.30	<3.00	0.03	0.30	2.31	<0.50	41.40	0.13	<1.00	0.41	3.50	63.40
14	Shorthead redhorse	72.10	<0.20	12.00	3.00	0.19	1.60	2.40	<0.50	70.30	0.32	<0.10	0.80	3.80	80.90
14	Shorthead redhorse	68.20	<0.20	26.50	3.00	0.20	1.00	2.60	<0.50	73.40	0.49	<0.10	0.60	3.50	75.00

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Appendix Table 11. Concentrations ($\mu\text{g/g}$ dry weight) of elements detected in sediments from the Missouri River tributary streams in South Dakota, 1991.

Location	Arsenic	Barium	Boron	Cadmium	Copper	Chromium	Lead	Manganese	Mercury	Nickel	Selenium	Zinc
Grand River												
Highway 73	7.2	130.0	46.0	<2.0	11.0	2.3	21.0	720.0	<1.0	26.0	<1.0	55.0
West of Highway 63	17.0	170.0	43.0	<2.0	10.0	2.3	<10.0	610.0	<1.0	30.0	<1.0	68.0
Moreau River												
Highway 63	11.0	180.0	34.0	<2.0	9.8	2.5	<10.0	640.0	<1.0	28.0	<1.0	71.0
Highway 73	11.0	220.0	39.0	<2.0	8.1	2.3	<10.0	900.0	<1.0	28.0	<1.0	54.0
Bad River												
Ft. Pierre, South Dakota	7.6	470.0	35.0	<2.0	31.0	12.0	<10.0	1,900.0	<1.0	50.0	<1.0	130.0
Phillip, South Dakota	4.0	280.0	27.0	<2.0	16.0	12.0	<10.0	320.0	<1.0	22.0	<1.0	66.0
White River												
At Lake Francis Case	2.9	340.0	15.0	<2.0	7.9	4.8	<10.0	510.0	<1.0	8.7	<1.0	34.0
Highway 73	1.5	400.0	15.0	<2.0	7.3	4.4	<10.0	430.0	<1.0	11.0	<1.0	30.0

Appendix Table 12. Concentrations ($\mu\text{g/g}$ dry weight) of mercury, arsenic, and selenium in sediments from Foster Bay on the Cheyenne River arm of Oahe Reservoir, 1984.

Mercury	Arsenic	Selenium
13.0	10.0	0.7
10.0	9.5	0.5
9.9	10.0	0.6
7.0	6.7	0.3
13.0	9.7	0.6
14.0	20.0	3.7
15.0	10.0	0.5
11.0	10.0	0.6
15.0	9.5	0.7
15.0	6.6	0.7
11.0	30.0	0.5
11.0	12.0	0.6
3.0	2.2	0.2
7.5	5.2	<0.2
16.0	9.8	0.5
5.5	7.0	0.2
7.4	3.9	0.3
10.0	13.8	<0.2
9.1	7.6	<0.2
10.0	50.0	0.3
8.8	39.0	0.4
10.0	65.0	0.5

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Appendix Table 13. Concentrations ($\mu\text{g/g}$ dry weight) of elements in sediments from the Missouri River in South Dakota.

Location	Arsenic	Barium	Boron	Cadmium	Copper	Chromium	Lead	Manganese	Mercury	Nickel	Selenium	Zinc
Lake Oahe												
Upper ^a									0.05		0.76	
Lower ^a									0.06		0.52	
Lake Sharp												
Upper ^a									0.06		0.64	
Lower ^a									0.07		0.77	
Lake Francis												
Case Upper ^a									0.02		0.46	
Lower ^a									0.06		2.78	
Lewis and Clark Lake ^a									0.05		2.32	
RKM 1221.2		534.00		0.55	8.32	21.90	20.60	740.00	0.59	16.00	0.59	40.30
RKM 1222.8	4.60	150.00	14.00	<2.00	5.20	4.50	<10.00	360.00	<1.00	17.00	<1.00	33.00
RKM 1230.1	9.20	120.00	13.00	<2.00	<5.00	3.80	<10.00	260.00	<1.00	14.00	<1.00	30.00
RKM 1271.9	5.60	170.00	21.00	<2.00	9.70	5.70	<10.00	1,100.00	<1.00	25.00	<1.00	52.00
RKM 1277.5		434.00		<0.05	5.44	16.20	14.00	548.00	0.80	14.00	0.80	32.00
RKM 1280.8		461.00		0.98	12.30	27.00	25.50	1,380.00	0.08	22.10	0.80	53.70
RKM 1284.0	5.20	120.00	14.00	<2.00	<5.00	2.50	<10.00	310.00	<1.00	12.00	<1.00	28.00
RKM 1285.6		346.00		<0.05	3.63	7.60	14.50	533.00	0.62	10.10	0.62	19.60
RKM 1288.8	7.30	120.00	12.00	<2.00	<5.00	2.80	<10.00	320.00	<1.00	12.00	<1.00	26.00
RKM 1338.7	7.40	84.00	12.00	<2.00	<5.00	3.60	<10.00	350.00	<1.00	15.00	<1.00	28.00
RKM 1340.3		570.00		0.74	4.33	17.50	20.80	524.00	<0.03	14.40	<0.30	32.90
RKM 1351.6	3.70	110.00	8.60	<2.00	<5.00	2.60	<10.00	320.00	<1.00	7.50	<1.00	21.00
RKM 1356.4	1.80	28.00	<5.00	<2.00	<5.00	<2.00	<10.00	120.00	<1.00	<5.00	<1.00	8.20
RKM 1370.1	8.70	160.00	15.00	<2.00	<5.00	3.40	<10.00	380.00	<1.00	15.00	<1.00	32.00

^a Data from Phillips et al. (1987) showing the mean values for Mercury and Selenium in 13 to 30 sediment samples collected in 1980. Data by river kilometer (RKM) are for samples collected from the Missouri River islands in 1990 by the U.S. Fish and Wildlife Service.

Appendix Table 14. Concentrations ($\mu\text{g/g}$ wet weight) of mercury and selenium in individual livers from adult and juvenile double-crested cormorants collected from the upper Cheyenne River arm of Oahe Reservoir in 1984.

	Mercury	Selenium
Adult	1.90	7.20
	36.00	21.00
	23.00	8.60
	26.00	14.00
Juvenile	1.20	3.10
	1.30	1.30
	0.83	4.10
	0.38	4.80
	0.59	6.70
	1.00	3.30

Appendix Table 15. Mean mercury concentrations ($\mu\text{g/g}$ wet weight) in composite, edible tissue samples of northern pike, walleye, channel catfish, and common carp from Lake Oahe, 1970-71. Number of fish in parentheses. Data from U.S. Environmental Protection Agency (1971b)

Location	Northern pike	Walleye	Channel catfish	Common carp
Upper Cheyenne River arm of Oahe Reservoir	0.65 (12)	0.51 (18)	0.34 (14)	0.38 (18)
Whitlock Bay	0.40 (5)	0.16 (15)	0.23 (19)	0.22 (16)
Oahe tailwaters	0.20 (2)	0.12 (18)	0.21 (12)	0.15 (7)

Appendix Table 16. Mercury, arsenic, and selenium concentrations ($\mu\text{g/g}$ wet weight) in whole fish and mercury in edible tissues of fish from Foster Bay on the Cheyenne River arm of Oahe Reservoir, South Dakota, 1984. Data from Sowards (1985).

	Percent moisture	Mercury	Arsenic	Selenium	Mercury in edible tissue
Northern pike	74.70	2.20	0.09	0.76	0.32
	71.50	0.16	0.16	0.75	0.15
	74.60	0.16	0.10	1.30	0.19
	74.90	0.14	0.21	0.85	0.09
	73.10	0.19	0.16	0.60	0.15
	70.70	0.16	0.12	1.00	0.14
	75.20	0.16	0.08	0.68	0.14
	74.70	0.13	<0.05	1.20	0.15
	72.30	0.27	0.07	0.62	0.17
	74.90	0.16	0.09	0.77	0.21
	Mean ^a	0.37	0.11	0.85	0.17
Walleye	65.70	0.20	0.31	0.66	0.33
	70.40	0.25	0.26	0.49	0.30
	71.00	0.26	0.34	1.10	0.16
	69.80	0.20	0.25	0.85	0.12
	68.90	0.30	0.27	0.68	0.38
	67.40	0.21	0.31	0.66	0.19
	66.70	0.34	0.41	0.44	0.16

Appendix Table 16. *Continued*

	Percent moisture	Mercury	Arsenic	Selenium	Mercury in edible tissue
	67.40	0.24	0.38	0.49	0.34
	72.90	1.70	1.50	1.20	0.17
	69.60	0.19	0.35	0.51	0.26
Mean ^a	68.98	0.39	0.44	0.71	0.24
Common carp	76.60	0.21	0.21	1.30	0.25
	77.20	0.15	0.17	1.90	0.34
	79.00	0.15	0.10	1.30	0.20
	73.80	0.12	0.18	1.40	0.16
	77.40	1.20	0.13	1.60	0.27
	78.40	0.18	0.12	1.20	0.16
	79.50	0.09	0.07	1.20	0.11
	78.10	0.23	0.07	1.60	0.25
	79.10	0.24	0.17	0.97	0.24
	69.30	0.18	0.25	0.96	0.34
Mean ^a	76.84	0.28	0.15	1.34	0.23
Channel catfish	75.80	0.08	<0.05	0.50	<0.05
	72.50	0.14	0.06	0.44	0.11
	64.20	0.12	<0.05	0.54	0.10
	82.80	0.07	<0.05	0.70	0.15
	78.10	0.10	<0.05	0.75	0.16
	74.20	0.23	<0.05	0.58	0.14
	79.00	0.06	<0.05	0.70	<0.05
	76.80	0.16	0.04	0.45	
	71.90	1.80	<0.05	0.33	0.35
	76.30	0.11	<0.05	0.48	
Mean ^a	75.16	0.29	0.03	0.55	0.13

^a Half the detection level was used to calculate the means for elements not detected.

Appendix Table 17. Concentrations (mg/kg dry weight) of inorganic elements detected in forage fish collected in 1990 from islands on the Missouri River in South Dakota.

River kilo- meter	Percent moisture	Selenium	Mercury	Cadmium	Chromium	Copper	Manganese	Nickel	Lead	Zinc	Barium
1221.2	80.00	3.83	<0.05	0.194	2.47	4.55	93.20	2.24	1.60	120.00	51.10
1277.5	86.90	3.78	<0.05	0.135	6.22	3.05	120.00	3.29	<1.50	152.00	101.00
1280.8	81.70	2.28	<0.05	<0.010	2.33	2.90	170.00	4.85	2.47	91.30	38.50
1285.6	86.30	3.53	<0.05	0.565	3.66	4.12	411.00	4.43	3.47	149.00	195.00
1340.3	75.60	4.82	<0.05	0.180	1.62	2.93	24.30	0.50	<1.50	127.00	9.51

END

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